PB89-124416

Incineration of a Chemically Contaminated Synthetic Soil Matrix (SSM) Using a Pilot-Scale Rotary Kiln System

PEI Associates, Inc., Cincinnati, OH

Prepared for

Environmental Protection Agency, Cincinnati, OH

Nov 88

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/D-88/240	2.
3. RECIPIENT'S ACCESSION NO. PB89 124416/AS	
4. TITLE AND SUBTITLE INCINERATION OF A CHEMICALLY CONTAMINATED SYNTHETIC SOIL MATRIX (SSM) USING A PILOT-SCALE ROTARY KILN SYSTEM	5. REPORT DATE November 1988
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) M.P. Esposito, M.L. Taylor, C.L. Bruffey and R.C. Thurnau	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS USEPA, HWERL Cincinnati, OH 45268 PEI Associates, Inc. Cincinnati, OH 45246	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-03-3389
12. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory Office of Research and Development U.S. EPA Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Hazardous and Solid Waste Amendments (HSWA) of 1984 prohibit the continued land disposal of untreated hazardous wastes beyond specified dates. The statute requires EPA to set "levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized." The legislation sets forth a series of deadlines at which time further disposal of particular waste types is prohibited if the Agency has not set treatment standards under Section 3004(m) or determined, based on a case-specific petition, that there will be no migration of hazardous constituents for as long as the wastes remain hazardous.

This paper details part of the initial work conducted from June to November 1987 under Phase I of EPA's Superfund research program. In this segment of the program, a surrogate Superfund soil bearing a wide range of chemical contaminants typically occurring at Superfund sites was subjected to treatment by rotary kiln incineration. A series of 6 test burns were conducted, a complete set of process and emissions samples were collected and analyzed, and the results are reported herein.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 31
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE PC $13.95 / MF $6.95

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

PB89-124416

EPA/600/D-88/240
November 1988

INCINERATION OF A CHEMICALLY CONTAMINATED SYNTHETIC SOIL MATRIX (SSM) USING A PILOT-SCALE ROTARY KILN SYSTEM

By

M. P. Esposito, M. L. Taylor, and C. L. Bruffey
PEI Associates, Inc.
Cincinnati, OH 45246

R. C. Thurnau
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

EPA Contract 68-03-3389

EPA Project Officer
R. C. Thurnau

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Incineration of a Chemically Contaminated Synthetic Soil Matrix (SSM)Using a Pilot-Scale Rotary Kiln System

M. P. Esposito, M. L. Taylor and C. L. Bruffey
Environmental Technology Department, PEI Associates, Inc.
Cincinnati, Ohio 45246

R. C. Thurnau
Risk Reduction Engineering Laboratory, Environmental Protection Agency
Cincinnati, Ohio 45268

INTRODUCTION

The Resource Conservation and Recovery Act (RCRA) Hazardous and Solid Waste Amendments of 1984 (HSWA) prohibit the continued land disposal of untreated hazardous wastes beyond specified dates. The statute requires the U.S. Environmental Protection Agency (EPA) to set "levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized." In addition to addressing future land disposal of specific listed wastes, the RCRA land disposal restrictions also address the disposal of soil and debris from Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) site response actions. Sections 3004(d) (3) and (e) (3) of RCRA state that the soil/debris waste material resulting from a Superfund-financed response action or an enforcement authority response action implemented under Sections 104 and 106 of CERCLA, respectively, will become subject to the land ban on November 8, 1988.

Because Superfund soil/debris waste often differs significantly from other types of hazardous waste, the EPA is developing specific RCRA Section 3004 (m) standards or levels applying to the treatment of these wastes. These standards will be developed through the evaluation of best demonstrated and available technologies (BDAT). In the future, Superfund wastes in compliance with these regulations may be deposited in land disposal units; wastes not meeting the standards will be banned from land disposal unless a variance is issued.

In early 1987, EPA's Hazardous Waste Engineering Research Laboratory (now known as the Risk Reduction Engineering Laboratory), at the request of the Office of Emergency and Remedial Response, initiated a research program to evaluate various treatment technologies for contaminated soil and debris from Superfund sites. Under Phase I of this research program, which was conducted from April to November 1987, a synthetic soil matrix (SSM) was spiked with chemical contaminants typical of those found at Superfund sites. Portions of the chemically-spiked SSM were implemented in bench-scale and pilot-scale performance evaluations of five available treatment technologies including 1) soil washing, 2) chemical treatment (KPEG), 3) thermal desorption, 4) incineration, and 5) stabilization/fixation. This paper covers those segments of Phase I related to preparation and spiking of the SSM and evaluation of incineration as a treatment technology. As part of this technology evaluation, a complete series of pilot-scale test burns was conducted and a battery of process and emission samples were collected and analyzed. Results of these tests are described herein.

METHODS AND EXPERIMENTAL

Preparation and Spiking of the SSM

The soil matrix components of the SSM (see Table 1) were selected on the basis of an extensive review of soil composition data from nearly 100 Superfund sites from various Regional locations. The soil was prepared by first air drying the components to minimize moisture, then mixing the components together in a standard truck-mounted six cubic-yard cement mixer to obtain two identical 15,000 pound batches. This operation was completed at an Ohio sand and gravel quarry using standard process equipment. The SSM was then dispensed in 500 pound quantities into epoxy-lined, 55-gallon steel drums, loaded on a flatbed truck, and transported to EPA's Center Hill Research Facility in Cincinnati, Ohio where the chemicals (or analytes) were added. Analysis of the SSM revealed that it had a pH of 8.5, and a cation exchange capacity of 133

meq/100ml. It was also checked for contaminants appearing on EPA's Hazardous Substance List and found to be contaminant-free. [1]

Table 1. Clean Soil Formula

Percent (by volume)	Component
30	Clay *
25	Silt
20	Sand
20	Topsoil
5	Gravel
—	
100%	

*Bentonite and Montmorillonite

The chemicals which were subsequently added to the SSM were selected to be representative of specific compounds or classes of chemical compounds typically found in contaminated soils at Superfund sites. The organic chemicals added included ethylbenzene, acetone, 1,2-dichloroethane, tetrachloroethylene, chlorobenzene, styrene, xylene, anthracene, pentachlorophenol, and bis (2-ethylhexyl) phthalate. Salts or oxides of the following inorganic were also added: lead, zinc, cadmium, arsenic, copper, chromium, and nickel. In order to challenge the incineration system with both a high and a low range of contaminant concentrations, such as occur at typical Superfund sites, two different spiked soil formulations were prepared in which the concentration of the targeted organic contaminants/analytes differed by a factor of 10X; i.e., total organic contaminants were set at approximately 30,000 mg/kg in one

formulation of spiked SSM and 3,000 mg/kg in the other formulation. The level for the inorganic contaminants was set at 1000 mg/kg in both formulations. Table 2 provides a complete listing of the contaminant concentrations targeted for each formulation. Nearly 14,000 pounds of each of the two formulations of spiked SSM were prepared in July and August of 1987 for the test burns which were subsequently conducted in September of 1987.

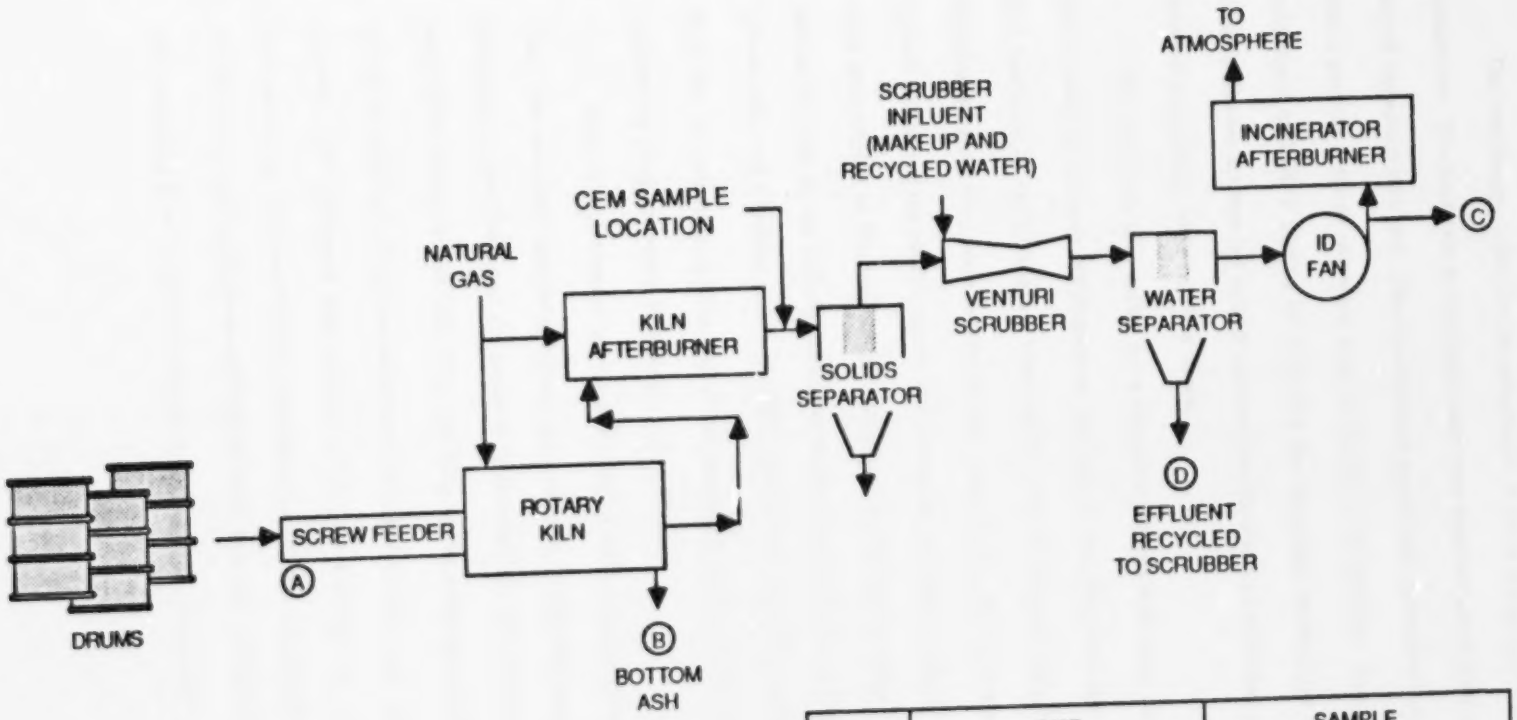
Incineration Test Facility

The series of test burns was conducted at the John Zink Company's RCRA-permitted testing facility located in Tulsa, Oklahoma. The test facility consists of several pilot-scale modular components which can be assembled in a variety of configurations.

For this test series, a rotary kiln system was used as shown schematically in Figure 1. The system consisted of a refractory-lined rotary kiln 15 feet in length and 5 feet in outside diameter, fitted with a natural gas fuel burner, a screw conveyor for feeding bulk solids, and a continuous bottom ash removal and quench system. Gases from the kiln were ducted to a horizontal secondary combustion chamber (10 feet in length, 4.5 feet in outside diameter, and fitted with a natural gas burner), a cyclone separator for removal of large particulates in the gas stream, a gas quench section, an adjustable venturi scrubber, and an induced-draft fan. For this test, the rotary kiln was positioned for co-current operation; i.e., the solids/ash travelled in the same direction as the combustion gases. The entire system operated under negative pressure to avoid fugitive losses to the atmosphere. In addition to this equipment, a tertiary afterburner (required by the Oklahoma State Department of Health for final thermal treatment of the secondary combustion system's flue gas) followed the air pollution control equipment . All sampling for this test program was conducted upstream of the tertiary unit.

Table 2. Target Contaminant Levels for Synthetic Soils Used as Waste Feed

Contaminant	Soil I mg/kg	Soil II mg/kg
Volatiles		
Ethylbenzene	3,200	320
Xylene	8,200	820
Tetrachloroethylene	600	60
Chlorobenzene	400	40
Acetone	6,800	680
1,2-Dichloroethane	600	60
Styrene	1,000	100
	20,800	2,080
Semivolatiles		
Anthracene	6,500	650
Bis(2-ethylhexyl)phthalate	2,500	250
Pentachlorophenol	1,000	100
	10,000	1,000
Inorganics		
Lead	280	280
Zinc	450	450
Cadmium	20	20
Arsenic	10	10
Copper	180	180
Nickel	30	30
Chromium	30	30
	1,000	1,000



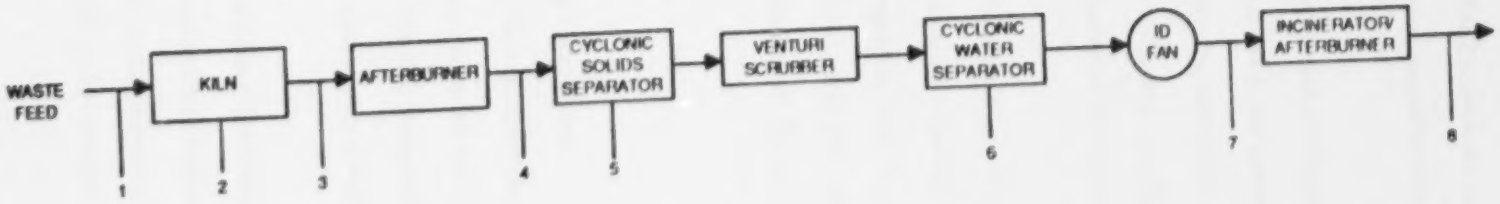
SAMPLE ID	SITE DESCRIPTION	SAMPLE DESCRIPTION
A	Drums	Waste Feed
B	Ash Bin	Bottom Ash
C	Sample Ports	Stack Gas
D	Water Separator	Scrubber Effluent

Figure 1. Schematic diagram of the John Zink Company's pilot-scale rotary kiln incineration system showing feed and residuals sampling sites (points A, B, C, and D).

The test design called for the completion of three 4-hour test burn runs for each SSM formulation. The feed rate to the incinerator was maintained at approximately 1000 pounds per hour of contaminated soil. The kiln rotation speed was maintained at 0.35 rpm throughout all tests to provide a solids retention time in the kiln of 45 minutes. The temperature of the kiln was maintained at 1800°F during all tests and the secondary combustion chamber was maintained at 2000°F. Excess air was fed to both combustion chambers at all times, and the scrubber water was recycled completely, with no blow down.

The test plan also called for a complete process and stack emission monitoring program. The volatile compounds ethylbenzene and xylene and the semivolatile compounds anthracene and bis(2-ethylhexyl)phthalate were designated as Principal Organic Hazardous Constituents (POHCs) because they were present in the waste feed in the largest amounts. These two compounds as well as each of the other organic and inorganic compounds which were added to the test soils were quantitated in the incinerator influent and effluent samples. Other parameters monitored during the test series included chlorinated dibenzo-p-dioxins and dibenzofurans in the waste feed, bottom ash, and scrubber water, and HCl, particulate, O_2, CO_2, and CO in the gas stream emerging from the air pollution system. All of the sampling and analysis methods utilized for the monitoring program were EPA-approved methods.

John Zink personnel operated the incineration system throughout the entire test program. They also provided standard system performance monitoring consisting of continuous temperature, gas flow, and O_2 monitoring through the kiln and secondary chamber, plus continuous monitoring of CO, CO_2, and NO_X in the stack gases exiting the tertiary burner. PEI personnel collected all process samples of soil feed, bottom ash, and scrubber water throughout each test run. PEI personnel also collected continuous stack gas samples from sample ports following the venturi for volatiles (VOST), semivolatiles (MM5), metals (EPA Method 12), HCl (EPA Method 5), CO, CO_2, and O_2 analyses throughout each test run. A chart showing the overall monitoring and sampling plan is shown in Figure 2. The sample ports used by PEI for stack testing purposes



SAMPLING POINT	PARAMETER											
	WASTE FEEDRATE	WASTE FEED	FUEL FEEDRATE	AIR FEEDRATE	ASH	SCRUBBER WATER	CONTINUOUS MONITORS CO2, O2, CO, T	VOLUME FLOW	VOST, MM5 (VOLATILES, SEMIVOLATILES AND METALS)	M5 (PARTICULATE AND HCl)	T	P
1	X	X	X	X								
2					X						X	
3			X	X							X	
4												
5					X							
6						X	X	X	X	X	X	X
7							X				X	
8[a]												

T: Temperature
P: Pressure
a: Monitoring by John Zink for state permit requirements

Figure 2. Operating parameters monitored during test burns.

were located in the flue between the venturi scrubber and the tertiary afterburner. The ports were 4 inches in diameter, located on a vertical, 12-inch I. D. section of flue about 15 feet above ground.

Prior to the start of each test, the combustion system was brought up to operating temperature by firing natural gas in the system for several hours. The process of feeding soil to the kiln was started only after the test system was operating satisfactorily at steady state condition. The auxiliary fuel firing rate was adjusted automatically by system controls to maintain a steady operating temperature throughout each run.

The 55-gallon drums of soil were staged on the hazardous waste storage pad located immediately adjacent to the test equipment. Drums were transported to the screw conveyor using a hydraulic drum lifter; once the drums has been emptied of feed material, they were used to containerize the bottom ash, which ultimately was sent for disposal to U.S. Pollution Control, Inc.'s Lone Mountain RCRA landfill in Oklahoma.

RESULTS

Operating Conditions

Two runs per day were conducted over the 3-day period of September 16, 17, 18, 1987. Runs 1, 2, and 3 were conducted with Soil Formulation I (high organics) and runs 4, 5, and 6 were conducted with Soil Formulation II (low organics). No significants problems with the incinerator system were encountered during these tests.

The process operating data collected during each test (see Table 3) indicate the temperatures and feed rates achieved were reasonably close to the test plan goals (i.e., 1800°F in the kiln, 2000°F in the secondary, and a nominal feed rate of 1000 pounds per hour). Excess air (measured as % O_2) was maintained at about 3 percent in the kiln and about 5 percent in the

TABLE 3. Summary of Process Operating Conditions

Location/parameter	Soil I				Soil II			
	Run 1	Run 2	Run 3	Average	Run 4	Run 5	Run 6	Average
Feed								
Time elapsed, hr:min	4:23	3:45	4:54	4:21	4:06	4:12	4:02	4:07
Amount fed, lb	4640	3939	5353	4644	4392	4561	4507	4487
Feed rate, lb/hr	1059	1060	1092	1067	1071	1086	1118	1092
Kiln								
Temperature range, °F	1764-1824	1745-1809	1725-1770	1745-1801	1706-1777	1754-1804	1764-1799	1741-1793
Average temperature, °F	1795	1776	1760	1777	1749	1784	1780	1771
O2, %	3.3	4.7	2.5	3.5	2.6	3.3	2.4	2.8
Secondary Chamber								
Temperature range, °F	1942-2038	1928-2008	1960-2008	1961-2018	1959-2004	1983-2014	1999-2010	1980-2009
Average temperature, °F	2004	1997	1995	1999	1985	2004	2005	1998
O2, %	4.1	6	4.6	4.9	4.1	5.4	5.2	4.9
Scrubber								
Flow, % max	72	70	76	73	72	72	70	71
Blowdown, % max	0	0	0	0	0	0	0	0
Pressure drop (venturi), in. w.g.	23	25	24	24	26	23	23	24
Stack								
O2, %	5.8	6.3	6.1	6.1	5.1	5.9	5.3	5.4
CO2, %	10.1	9.6	10.2	10	10.9	10.4	11.1	10.8
CO, ppm	<10	<10	<10	<10	<10 (a)	<10 (b)	<10	<10

(a) On three occasions, CO spiked to 90, 69, and 69 ppm for about one minute each occurrence.

(b) On two occasions, CO spiked to 45 ppm briefly (less than 5 minutes each).

secondary chamber during both tests. Emissions of O_2, CO_2, and CO were steady throughout; CO remained at less than 10 ppm at all times except for a few brief excursions of 45 to 90 ppm, which lasted from 1 to 5 minutes. A total of 13,932 pounds of Soil I and 13,460 pounds of Soil II were incinerated over a course of 3 days that involved 29 hours and 22 minutes of testing.

Process Sample Results

Process samples of waste feed, bottom ash, and scrubber water that were ultimately analyzed for semivolatiles and metals were collected as composites over the course of each test run. Samples analyzed for volatiles were collected as discrete samples at the beginning, middle and end of each run, and composited at the time of analysis.

Two approaches were utilized in analyzing the process samples that were collected during each test run. First of all, the samples were analyzed for the total content of each target analyte using EPA SW-846 methods. Second, TCLP procedures were used to develop leachability data for the waste feed and the bottom ash samples from each test run. The TCLP and total analyte analyses have both been used to develop conclusions about the treatment efficiency of incineration for contaminated soils, relative to the pending land ban provisions of HSWA.

Waste Feed Analyses

Table 4 lists the data obtained through total analysis of the waste feed/soil samples collected during the test program; the concentrations found for most of the analytes were reasonably close to the desired targets, although some of the organics were on the low side of the targeted values.

TABLE 4. Total Analysis of Soil Feed*

Analyte	Method Detection Limit	Soil I				Soil II			
		Run 1	Run 2	Run 3	Average	Run 4	Run 5	Run 6	Average
Volatiles, mg/kg									
Ethylbenzene	7	3600	2400	4000	3333	240	84	330	218
Xylene	5	5800	4000	6000	5267	120	150	520	253
Tetrachloroethylene	4	(a)	260	350	305	29	8.5	36	25
Chlorobenzene	6	340	240	360	313	22	6.9	30	20
Acetone	8	3300	6000	2700	4000	680	570	270	507
1,2 Dichloroethane	3	450	140	340	310	13	3.5	28	15
Styrene	3	770	580	810	720	51	16	67	45
Semivolatiles, mg/kg									
Anthracene	6	6200	8500	5300	6667	480	420	440	447
Bis(2-ethylhexyl)phthalate	44	2800	3300	2200	2767	290	270	ND	187
Pentachlorophenol	3	ND	630	ND	-	ND	ND	ND	-
Metals, mg/kg									
Lead	4.2	261	296	292	283	328	301	302	310
Zinc	0.12	451	551	526	509	548	508	158	405
Cadmium	0.12	26	25	26	26	26	26	26	26
Arsenic	0.04	17	17	20	18	19	19	18	19
Copper	0.42	244	267	261	257	282	250	255	262
Nickel	0.3	28	30	27	28	30	28	28	29
Chromium	0.3	24	33	39	32	30	27	27	28
Average feed rate									
lb/h		1060	1062	1092	1071	1071	1096	1118	1092
kg/h		482	483	496	487	487	497	508	497
Moisture content (Dean Stark Distillation)									
% H2O			19.6				22.9		

* See Table 2 for target concentrations

(a) Analytical result rejected for QA reasons

ND = None detected

One notable exception is the group of results for pentachlorophenol (PCP). Five of the six feed samples failed to show any detectable concentration of the compound, even though it was known that PCP was added to each batch either at the 1000mg/kg level or at the 100 mg/kg level. One possible explanation for this may be related to the current SW-846 sample preparation method which calls for an acid digestion of the soil sample prior to analysis; reportedly, this digestion procedure is very ineffective in liberating PCP from the soil into the extract which is ultimately analyzed. [2]

Table 5 compares the results of the average total analysis of the waste feed soils to the results of the TCLP analysis for each soil (both values developed on samples of the untreated soil taken simultaneously from the feedstock during each test run). The table also lists the regulatory limits that have been proposed for several of the analytes. The data in Table 5 indicate that both untreated soils fail the TCLP test for volatiles, but pass for all of the inorganic contaminants.

Bottom Ash Analyses

Table 6 lists the results from analyses of the bottom ash samples collected during each of the test runs. The organic compounds chlorobenzene, styrene, tetrachloroethylene , anthracene, and pentachlorophenol were not detected in any of the ash samples, indicating that they were completely removed and/or destroyed. Measurable quantities of ethylbenzene and xylene were sometimes found in the ash of both soils and 1,2-dichloroethane was found in the ash produced during two of the three tests of Soil II; the amounts reported were very small (in the low parts-per-billion range) and within 2 to 3 times the method detection limit. Acetone was found in the ash samples of all runs for both soils at levels ranging from 190 to 790 µg/kg; these levels are 24 to 99 times higher than the method detection level (8µg/kg). Similarly, the phthalate analyte was found in the ash of all six runs at levels many times the method detection limit.

TABLE 5. Analytical Results for Untreated Soils (a)

Analyte	Soil I		Soil II		Proposed TCLP Regulatory Limit (mg/l)***
	Average Total Analysis (mg/kg)*	TCLP (mg/l)	Average Total Analysis (mg/kg)**	TCLP (mg/l)	
Volatiles					
Ethylbenzene	3333	49.7	218	7.31	---
Xylene	5267	84.6	253	15.8	---
Tetrachloroethylene	305	3.59	25	0.68	0.1
Chlorobenzene	313	6.47	20	0.79	1.4
Acetone	4000	282	507	26.1	---
1,2 Dichloroethane	310	18.9	15	0.48	0.4
Styrene	720	2.1	45	0.58	---
Semivolatiles					
Anthracene	6667	<0.01	447	<0.02	---
Bis(2-ethylhexyl)phthalate	2767	0.06	187	<0.06	---
Pentachlorophenol	210 (b)	0.98	N D	0.09	3.6
Metals					
Lead	283	0.46	310	1.74	5.0
Zinc	509	7.96	405	13.5	---
Cadmium	26	0.62	26	0.77	1.0
Arsenic	18	ND (0.15)	19	ND (0.15)	5.0
Copper	257	1.31	262	4.12	---
Nickel	28	0.34	29	0.65	---
Chromium	32	ND (0.01)	28	0.07	5.0

* Average of runs 1, 2 and 3

** Average of runs 4,5 and 6

*** Limits are those proposed in Federal Register Volume 51, Number 114, June 13, 1986.
Several analytes have no proposed regulatory limit; these are indicated by "---".

(a) See Table 4 for individual analyte values obtained during each run.

(b) ND in runs 1 and 3; 630 mg/kg in run 2.

TABLE 6. Total Analysis of Bottom Ash

Analyte	Method Detection Limit	Soil I			Soil II		
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Volatiles, µg/kg							
Ethylbenzene	7	ND (a)	19	ND	8	ND	13
Xylene	5	ND	34	ND	11	6	20
Tetrachloroethylene	4	ND	ND	ND	ND	ND	ND
Chlorobenzene	6	ND	ND	ND	ND	ND	ND
Acetone	8	440	420	630	190	210	790
1,2 Dichloroethane	3	ND	ND	ND	ND	5	10
Styrene	3	ND	ND	ND	ND	ND	ND
Semivolatiles, µg/kg							
Anthracene	37	ND	ND	ND	ND	ND	ND
Bis(2-ethylhexyl)phthalate	63	1600	540	740	950	710	1300
Pentachlorophenol	370	ND	ND	ND	ND	ND	ND
Metals, mg/kg							
Lead	4.2	56	98	107	146	75	88
Zinc	0.12	217	227	250	252	199	237
Cadmium	0.12	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Arsenic	0.04	38	36	44	46	39	37
Copper	0.42	111	132	159	125	106	162
Nickel	0.3	12	15	11	12	9	12
Chromium	0.3	10	14	12	12	7	10
Volatile PICs, µg/kg							
2-Butanone	25	35	ND	ND	14(b)	ND	ND
Methylene chloride	2.8	2.9	5.4	4.2	ND	ND	ND
2-Chloroethylvinylether	5	70	ND	ND	ND	ND	ND

(a) ND = Not detected

(b) Estimated value less than detection limit

The reported findings of ethylbenzene, xylene, 1,2-dichloroethane, acetone, and the phthalate in the ash should be viewed with caution. Because the first three compounds were found intermittently and typically at levels very close to the method detection level (MDL), the values reported could be considered noise or analytical error, and should not necessarily be viewed as positive evidence of the presence of these materials. The values reported for the latter two compounds cannot be dismissed as analytical noise because the concentrations reported were many times higher than the MDL; however, inspection of the numbers shows that the values reported for the ash of Soil I are very similar to those reported for the ash of Soil II, even though the input waste feed level for these compounds (acetone and phthalate) was roughly 10 times higher in Soil I than in Soil II. This is suggestive of sample contamination somewhere in the system, either in the field during sampling or in the lab during analysis.[3] It is also noteworthy that significant quantities of phthalate were found during analysis in several of the method blanks, and both acetone and phthalates are well known contaminants that inadvertantly show up in chemical analysis.

The total metals data for the ash samples are perhaps the most interesting. Prior to testing, it was anticipated that most of the metal concentrations in the ash would tend to be elevated compared to the waste feed, due to the combined effects of retention of metals in the ash and losses of water and organics from the feed during the incineration process. Cadmium levels in the ash, however, were anticipated to be lower due to volatilization of the metal in the kiln at the high operating temperature of 1800°F. As expected, cadmium levels in the ash were low, at least 99.9 percent lower than the waste feed levels. Surprisingly, all of the other metal levels except for arsenic were also considerably lower in the ash (on the order of 50-80 percent lower) than in the

[3] Ash samples were recovered directly from the kiln prior to the water quench, at the beginning, middle and end of each run, and placed in 5-gallon steel pails to cool prior to compositing and placement in glass laboratory sample jars for shipment to the laboratory for chemical analysis. It is possible that the metal can was the source of the phthalate contamination, but this has not been verified.

waste feed. Arsenic levels, on the other hand, were more than double those found in the feed. Table 7 provides a comparison of the metals data in the ash relative to the original feed for Soil I; similar results were obtained for Soil II, which had essentially the same levels of metals in the feed and ash.

Table 7. Soil I Bottom Ash: Total Waste Analysis Results for Metals

Analyte	Average Amount Found in Feed Runs 1-3, mg/kg	Average Amount Found in Ash Runs 1-3, mg/kg	Percent Remaining in Ash
Arsenic	18	39	217
Cadmium	26	<0.2	<0.1
Chromium	32	12	33
Copper	257	134	52
Lead	283	87	31
Nickel	28	13	46
Zinc	509	231	45

Table 8 presents the results of TCLP analyses of the ash samples taken during the first run of each soil; the table also lists the previously mentioned TCLP values for the untreated soils (waste feed) and the proposed regulatory limits for various contaminants. The data clearly show that the ash produced by incinerating both soils meets the proposed regulatory TCLP limits for all organics as well as all metals, whereas both of the untreated soils failed the TCLP test for organics.

TABLE 8. TCLP Values, mg/liter *

Analyte	Soil I		Soil II		Proposed regulatory limit mg/liter *
	Untreated (waste feed) Run 1	Treated (bottom ash) Run 1	Untreated (waste feed) Run 4	Treated (bottom ash) Run 4	
Volatiles					
Ethylbenzene	49.7	0.65	7.31	0.19	-
Xylene	84.6	1.05	15.8	0.23	-
Tetrachloroethylene	3.59	0.04**	0.68	ND (0.10	0.1
Chlorobenzene	6.47	0.04**	0.79	ND (0.10)	1.4
Acetone	282	0.74	26.1	0.14	-
1,2-Dichloroethane	18.9	ND (0.10)	0.48	ND (0.10)	0.4
Styrene	2.1	0.11	0.58	ND (0.10)	-
Semivolatiles					
Anthracene	<0.01	<0.01	<0.02	<0.01	-
Bis(2-ethylhexyl)phthalate	0.06	<0.01	<0.06	<0.01	-
Pentachlorophenol	0.98	<0.02	0.09	<0.02	3.6
Metals					
Lead	0.46	ND (0.15)	1.74	ND (0.15)	5
Zinc	7.96	ND (0.03)	13.5	0.49	-
Cadmium	0.62	ND (0.01)	0.77	ND (0.01)	1
Arsenic	ND (0.15)	ND (0.15)	ND (0.15)	ND (0.15)	5
Copper	1.31	ND (0.02)	4.12	0.26	-
Nickel	0.34	ND (o.04)	0.65	0.05	-
Chromium	0.01	ND (0.01)	0.07	0.04	5

ND = Not detected; numbers in parentheses ( ) indicate detection limit

* Federal Register, Vol. 51, No. 114, June 13, 1986

** Less than detection limit; estimated value

Scrubber Water Analyses

Table 9 presents the results of analyses of the scrubber water samples collected prior to and during each test run for total organic and inorganic analytes. The analyses indicate that the scrubber water was essentially free of all organics from the Soil I and Soil II feeds, except for acetone, which appeared in Runs 2 and 3 at low ppb levels, and phthalate which appeared in four of the six runs, also at low ppb levels. In both cases, the amounts detected were only 2-3 times the method detection limits. Pentachlorophenol was also detected in the scrubber water from two of the three runs on Soil I, at 4 and 8 ug/liter, levels which are 10-20 times higher than the MDL. Two volatile compounds which were not added to the waste feed, chloroform and bromodichloromethane, were detected at low ppb levels both in the influent scrubber water prior to the start of the tests and throughout the test runs.

The metals data for the scrubber water have been partially evaluated. The total volume of water that recirculated through the scrubber system has been estimated at 400 gallons, with evaporative losses made up at the rate of about 4 gallons per minute. The water was recirculated continuously through runs 1-6 without any discharge or blowdown. Assuming all of the metals scrubbed from the stack gases were retained in the scrubber water (i.e. that there was no carryover with the evaporative losses), the values reported from analysis of the scrubber water sample taken during run 6 should be indicative of the total metals capture by the scrubber water over the course of the six runs. Calculations utilizing the average metals content of the waste feed, the total amount of soil fed, the values reported in the scrubber water from run 6, and the total estimated volume of

Table 9. Total Analysis of Scrubber Water

Analyte	Method Detection Limit	Soil I			Soil II			
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Influent*
Volatiles, µg/liter								
Ethylbenzene	7	ND**	ND	ND	ND	ND	ND	ND
Xylene	5	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	4	ND	ND	ND	ND	ND	ND	ND
Chlorobenzene	6	ND	ND	ND	ND	ND	ND	ND
Acetone	8	ND	17	12	ND	ND	ND	ND
1,2 Dichloroethane	3	ND	ND	ND	ND	ND	ND	ND
Styrene	3	ND	ND	ND	ND	ND	ND	ND
Semivolatiles, µg/liter								
Anthracene	ND	ND	ND	ND	ND	ND	ND	ND
Bis(2-ethylhexyl)phthalate	3	ND	5	2.3	5	ND	9	ND
Pentachlorophenol	0.4	8	4	ND	ND	ND	ND	ND
Metals, µg/liter								
Lead	0.105	1.8	1.5	2.3	2.2	2	4.8	NA***
Zinc	0.003	2.1	4.4	1.8	2.9	1.7	3.3	NA
Cadmium	0.003	2.4	4.1	1.9	3.6	2	5.8	NA
Arsenic	0.001	0.15	0.26	0.15	0.27	0.18	0.41	NA
Copper	0.011	0.6	0.53	0.48	0.56	0.59	1.1	NA
Nickel	0.008	0.32	0.76	0.27	0.36	<0.04	0.27	NA
Chromium	0.008	2.4	4.1	1.9	3.6	2	5.8	NA
Other Compounds, µg/liter								
Chloroform	1.6	5.7	5.6	4.8	4.2	5.9	8.6	7.1
Bromodichloromethane	2.2	ND	ND	ND	ND	ND	2.4	2.7

* Sample of scrubber water collected prior to start of testing and analyzed for organic content only.

** ND = Not detected

*** NA = Not analyzed

scrubber water (400 gallons), have produced the following estimates of the percent metals retained by the scrubber water system during runs 1-6:

Metal	Percent
Cadmium	8.2
Chromium	6.7
Arsenic	1.3
Nickel	<0.8
Lead	0.6
Zinc	0.2
Copper	0.2

These results are being further studied in an attempt to fully understand the material balance around metallic contaminants that are incinerated with soils under these conditions.

Results of Dioxin and Furan Analyses

Waste feed, scrubber water, and ash samples taken during Runs 2 and 5 were analyzed for the presence of chlorinated dibenzo-p-dioxins and dibenzofurans (total tetra-, penta-, hexa-, and octa- chlorinated isomers) using EPA Method 8280 (SW-846, Third Edition). The analyses failed to detect the presence of dioxins or furans in any of the samples. All surrogate compound recoveries were within the limits specified by the method.

Air Emission Test Results

RCRA regulations require that hazardous waste incinerators meet certain requirements for particulate, HCl, and POHC emissions. The results of analyses of the stack samples collected during the Soil I and Soil II test burns indicate the particulate concentrations (corrected to 7 percent

O_2) were below the RCRA allowable limit of 0.08 gr/dscf for each soil. In additon the HCl emission rates (in pounds per hour) were considerably less than the RCRA allowable rate of 4.0 lb/h for each soil. Also, as noted previously, ethylbenzene, xylene, anthracene and bis(2-ethylhexyl)phthalate were designated POHCs for all test runs. As seen in Table 10, the destruction and removal efficiency (DRE) performance standard of 99.99 percent was achieved for three of the four designated POHCs (ethylbenzene, xylene, and anthracene) in all six runs. A DRE of 99.99 percent was achieved for the phthalate compound in three of the six runs; sample contamination (background level) problems are believed to be responsible for the poor DRE results in two of the other three runs. In one run, phthalate was not detected in the waste feed, preventing calculation of a DRE for that run.

The DRE of 99.99 percent or greater was achieved for the organic compounds (in addition to those discussed above) in Soil I in all three runs; for Soil II, which had the lower levels of organics, the 99.99 percent DRE was demonstrated in all three runs for acetone and dichloroethane, and in two out of three runs for chlorobenzene, styrene, and tetrachloroethylene. In several instances, acetone and dichloroethane could not be found in the stack gases; in these cases, the minimum method detection limits of 5 ng for acetone and 1 ng for dichloroethane were used to calculate the minimum DRE achieved. DREs could not be calculated for tetrachloroethylene in Run 1, phthalate in Run 6, and pentachlorophenol in Runs 1, 3, 4, 5, and 6 because of failure to detect the analytes in the waste feed samples; in the one run where pentachlorophenol was detected in the waste feed, a calculation was possible and the DRE exceeded 99.99 percent. The problems encountered in detecting the pentachlorophenol that was added to the waste feed are believed to be related to the analytical sample preparation procedures outlined in the SW-846 method that was used, as previously discussed.

TABLE 10. Summary of Organic DRE Data *[numbers shown as percent, see note (a)]*

Analyte	Soil I			Soil II		
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Volatiles						
Ethylbenzene	99.999	99.999	99.998	99.998	99.995	99.999
Xylene	99.999	99.999	99.998	99.992	99.99	99.998
Tetrachloroethylene	ND (b)	99.999	99.997	99.998	99.989	99.991
Chlorobenzene	99.998	99.999	99.995	99.996	99.988	99.996
Acetone	99.999	99.999	99.999	>99.999	>99.999	99.999
1,2 Dichloroethane	>99.99	99.999	99.998	>99.99	>99.99	99.998
Styrene	99.998	99.998	99.995	99.958	99.993	99.997
Semivolatiles						
Anthracene	>99.99	>99.99	>99.99	>99.99	>99.99	>99.99
Pentachlorophenol	ND (c)	>99.99	ND (c)	ND (c)	ND (c)	ND (c)
Bis (2-ethylhexyl) phthalate	99.99	99.999	99.967	99.992	99.6	ND (d)

ND = Not determined

(a) %DRE = [(mass in - mass out) / mass in] x 100

(b) Analytical result for total tetrachloroethylene in waste feed rejected for QA reasons

(c) None detected in the waste feed (detection limit 3.3 mg/kg) or in stack sample (detection limit 0.5 mg total)

(d) None detected in the waste feed (detection limit 44 mg/kg)

Table 11 shows the calculated percent loss of metals to the atmosphere from the Soil I feed stock used in Runs 1-3. These values were derived from total mass emission data and the total mass feed data for each metal. Cadmium proved to be the most volatile of the metals tested, with losses to the atmosphere of about 39 percent. Losses of the other metals , on average, were less than three percent each. Zinc, copper, and arsenic were found in the least amounts. Though not shown here, the metals emission results for Soil II were very similar to those for Soil I.

Table 11. Percent Loss of Metals to the Atmosphere for Soil I

Metal	Percent
Arsenic	0.52
Cadmium	39.
Chromium	1.3
Copper	0.48
Lead	1.7
Nickel	2.9
Zinc	0.40

Combustion gases in the stack emissions were continuously monitored during each test run for CO, CO_2, and O_2. Average values for each run are included in Table 3. Values for each analyte remained relatively steady throughout each test with only a few short-term excursion of one to five minutes . CO remained at less than 10 ppm at all times except during these excursions when it rose to 45-90 ppm. During the CO excursions, the O_2 content of the stack gas typically dropped to near zero percent . These events are believed to correspond to brief fluxes or surges in the feed rate of soil to the kiln.

CONCLUSIONS

These studies have shown that incineration can be a highly effective treatment method for soils containing a broad range of organic contaminants. The residual ash produced by incineration is likely to be considerably less hazardous than the untreated soil, as measured by the TCLP test, because the contaminants are either destroyed, removed, or otherwise altered so as to make them less likely to migrate from the treated residual when landfilled. The data from these tests indicate that under well controlled conditions, and given sufficient exposure to high temperatures, the organic contaminants likely to be encountered in contaminated soils resulting from response actions at Superfund sites can be destroyed and/or removed to levels meeting or exceeding 99.99 percent. However, the contaminants must be present in levels sufficiently high to allow calculation of the 99.99 percent DRE, and the analytical methods utilized must be highly sensitive to the analytes of concern.

Soils containing a mix of organic and metallic contaminants should be carefully evaluated before they are incinerated. These and other studies have produced evidence that some metals, such as cadmium, can volatilize in the process and be emitted in large part with the stack gases, even when efficient water-based scrubbing systems for particulate removal are employed. The inclusion of a more efficient gas cooling system prior to the scrubber or the addition of an electrostatic precipitator to the air pollution control system may improve the capture of volatile metals. Alternatively, lowering the incineration temperature should reduce the rate of metals volatilization, but the effect on DRE must not be compromised. Further studies in this area are needed.

ACKNOWLEDGMENTS

This work was funded in its entirety by the U. S. Environmental Protection Agency under Contract No. 68-03-3389, Work Assignment No. 7, R. Thurnau, Project Officer. PEI Associates, Inc., Cincinnati, Ohio, was the prime contractor with subcontractor support from Radian Corporation (sample analysis) and John Zink Company (test facility). Ms. Esposito, who is now with Bruck, Hartman, & Esposito, Inc., Cincinnati, Ohio, was the overall Technical Project Manager and Mr. Bruffey was the Stack Test Manager for PEI during the project.

The authors wish to acknowledge the assistance provided by Mr. Jake Campbell of John Zink Company throughout the planning and testing stages of the project, as well as during the preparation of this paper. His cooperation and guidance have been very valuable and are sincerely appreciated. The technical assistance provided by Mr. Ric Traver of the US EPA's Hazardous Waste Engineering Research Laboratory in Edison, N.J. during the preparation of the test soils is also gratefully acknowledged.

REFERENCES

1. PEI Associates, Inc. CERCLA BDAT SARM Preparation and Results of Physical Soil Washing Experiments. Final Report, Volumes I and II, EPA Contract No. 68-03-341, January 26, 1988.

2. Dr. Danny Jackson, Radian Corporation, Austin Texas, 4/7/88, Personal Communication.